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ARCTIC MARINE INVERTEBRATES AND OIL POLLUTION BY PIPELINE INQUIRY

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Relatively little attention has been paid to the ecological effects of development on components of the marine ecosystem that, while of little or no direct economic significance, nevertheless constitute the essential foundation of the ecological pyramid upon which the more visible elements are totally dependent for their very existence.

In this paper I am concerned chiefly with the direct impact of crude oil upon marine invertebrates. Emphasis is placed nevertheless of greater ecological significance over the long-term than the more readily observable rapid mortality at high oil concentrations.

The nature of the specific interaction of oil with the organisms is an important consideration. Crude oil, unlike many other pollutants, by virtue of its relative insolubility in seawater, does not spread uniformly through the environment from its point of release. I shall discuss primarily the sub-ice oil, the oiled sediments and the dispersed oil.

The most dramatic and obvious biological damage associated with oil spills in temperate and tropical waters occurs when drifting slicks are driven ashore and blanket large areas of the biologically rich intertidal zone. In most areas of the western arctic the intertidal zone



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is depressingly barren of marine life as a result of intense scouring by sea ice. Damage to invertebrate fauna in these areas will consequently be minimal. Such stranded oil is, however, still available for re-introduction into other areas of the marine environment, and should not be considered as completely innocuous.

Oil released under ice, or transported there by currents will tend to accumulate in irregularities in the ice undersurface to form oil lenses of variable size (Keevil and Ramseier, 1975). Accumulation of significant quantities of oil in under-ice habitat may have a number of very important ecological consequences.

A rich algal bloom forms on and within the lower surface of annual ice in spring (Apollonio, 1961; Horner and Alexander, 1972). This ice flora "forms an important fraction of the total production in the Arctic Ocean and....it helps greatly to prolong the productive season beyond that of the water-borne phytoplankton" (Dunbar, 1975). In addition, a variety of marine invertebrates have been observed congregating in the general vicinity of the ice-water interface (Green and Steele, 1975; Percy, 1975). The algal bloom may

serve as an important food source for some species during the spring, a time when phytoplankton levels in the water column are very low.

Although the algal components of such sub-ice communities have received considerable attention recently little is known about the potential impact of crude oil on these phytoplankton. Virtually nothing is known regarding the general ecology and trophic inter-relationships of the animals components of this community and little is known about the sensitivity of the animals to crude oil. The impact of oil on organisms in the sub-ice habitat may, in some respects, be similar to the impact on intertidal fauna in other areas. In both situations animals are likely to be subjected to smothering and fouling by viscous oil masses.

A particularly disturbing aspect of the accumulation of oil in pockets under and within the sea ice is that the trapped oil does not appear to weather significantly over the course of many months. The reason generally cited for the relatively limited impacts of crude oil spills in temperate and tropical waters is that the oil weathers very rapidly and loses most of the toxic components while drifting as a slick upon the sea surface. This appeared to be the case in the Torrey Canyon oil spill (Smith, 1970). Clearly this

could be re-introduced into the water column en masse. In view of the initiation of intense biological activity in the water column during the post break-up period this may be the worst possible time of the year for the reintroduction of unweathered oil into the seawater. Planktonic larval stages of many species may be particularly vulnerable at this time of year.

The high sediment load carried by the Mackenzie River into the Beaufort Sea, in the form of a massive and visually impressive plume, poses special problems in terms of the consequences of a major oil spill in the areas. The Santa Barbara blowout in California proved rather instructive in this respect. Heavy rains prior to this spill resulted in a heavy run-off that produced large sediment plumes in insnore areas. Oil slicks penetrated only short distances into such plumes and much of the oil was absorbed on suspended particles and carried to the bottom (Kolpack, 1971). In effect, the sediment acted as a natural sinking agent. At first glance this might appear to be a rather effective self-purification process. In fact, it appears to compound the problem immeasurably. Unlike an oil slick, oil bound to bottom sediments is essentially beyond human control. Sinking does not remove the oil from the ecosystem, rather it concentrates it in one ecologically important part of the marine environment.

Little is known about the effect of such oil-contaminated sediments upon benthic epifauna and infauna.

The present studies indicate that certain benthic species are killed by short-term exposure to oiled sediments, but only at very high oil concentrations; concentrations unlikely to be realized in the natural environment, except perhaps in close proximity to a spill. At present we have no information on possible toxic effects resulting from prolonged exposure to sediments tainted with lesser quantities of oil.

Of considerable ecological concern is the fact that certain species are capable of detecting low concentrations of oil in the sediment. Behavioral patterns may be markedly altered in the presence of such tainted sediment.

Blumer (1970) suggested that the high lobster mortality associated with one oil spill may have resulted from attraction of animals to the spill site. Our studies indicate that different benthic species respond quite differently to the presence of contaminated sediments. The burrowing amphipod Onisimus affinis exhibits a decided preference for untainted relative to tainted sediments. However, there are indications that at high oil levels the animals lose the ability to discriminate, possibly a consequence of chemical impairment of chemoreceptor function. On the other

hand, another benthic amphipod Corophium clarencense burrows readily in both untainted and tainted sediments. Clearly such behavioral responses will play an important role in determining the overall impact of pollution upon particular species.

Once oil is bound into superficial bottom sediments it is likely to have a long term effect on the benthic community. Studies in temperate areas suggest that oil trapped in sediments is degraded very slowly (Blummer and Sass, 1972). Given the sub-zero temperatures of arctic marine sediments the rate of degradation may be even slower. The present study indicates furthermore that the rate of decline in toxicity of sediment-bound oil varies markedly with different oil types.

Oil contaminated bottom sediments may not be static. Sediments in the Beaufort Sea are intermittently eroded and redeposited by bottom currents (Pelletier, 1974), so that the potential exists for contamination of a much wider areas of sea floor that affected by the initial deposition. In the Santa Barbara spill, oil initially deposited in shallow water was later transported and redeposited in deeper areas (Kolpack, 1971). Oil may occur in the water column in both a dispersed and a dissolved state, and it is in these forms that is it likely to spread most widely through the eco-

system and interact with the greatest number of species, It is generally agreed that the finely dispersed oil is more toxic to marine life than are soluble extracts.

This may, however, be largely due to the fact that much higher concentrations of oil occur in seawater in a dispersed form than in a dissolved form. The droplets, once formed can be rapidly dispersed over a considerable distance and to great depths as reported by Freegarde (1968) and Conover (1971). Several days after the wreck of the tanker 'Arrow', subsurface particulate oil was detected some 250 km from the scene of the spill (Forrester, 1970). Berridge et. al. (1968) point out that when water is the continuous phase there is no real limit to the extent to which the droplets are able to disperse.

Little useful information is available about the concentrations of oil to which arctic neritic species might be exposed, and for what length of time; both critical factors in assessing potential toxic effects.

In the case of a 65,000 barrel spill from a drilling rig in the Mississippi delta, the concentration of dispersed oil in the water column ranged from 1-70 ppm within a one mile radius of the spill (McAuliffe et al., 1975).

On the basis of the short-term lethal studies most of the species appeared to be relatively tolerant of high concentrations of dispersed crude oil. Even with the so called "sensitive" species dispersed oil concentrations of 100 ppm or greater were required to cause significant mortality during four days continuous exposure. It is unlikely that such high concentrations will occur widely in the water column, but may be reached in limited areas in close proximity to a spill, or where large accumulations of sub-ice oil are released into the seawater at break up.

It should also be kept in mind in extrapolating laboratory results to the field situation that the experimental toxicity tests reported here were routinely carried out with fresh crude oil that was replaced at 24 hour intervals. Consequently, the experimental results are based on the worst possible exposure conditions that could conceivably occur. Exposure of the oil at the sea-air interface for any length of time would undoubtedly result in a gradual reduction in toxicity through weathering.

In view of the above considerations it appears certain that massive short-term mortality among adult organisms inhabiting the neritic zone, as a consequence of contact with particulate or sub-particulate crude oil, if it occurs at all, be limited to relatively small

areas. Further, only particularly sensitive species are likely to be severely affected over the short-term, within these areas.

It is likely that given the right conditions some reduction in the diversity of species in the area would occur. This may be a particularly important consideration in the Beaufort Sea and perhaps the Arctic in general. For as Grainger (1975) points out, "the relatively simple population structure in inshore waters in particular suggests a relatively uncomplicated food chain, and this means fewer but relatively more important links in the chain and greater vulnerability on the whole than one would expect in a more complex web." At present we know too little about Arctic marine food chains to be able to confidently pinpoint critical links that might be particularly subject to disruption by spilled oil. Intensive studies on the trophic interrelationships of arctic marine organisms are clearly required.

The short-term lethality studies tend to indicate a rather high tolerance level for crude oil among the various species examined. However, a closer examination of the more subtle sublethal effects upon physiological functioning suggests that the oil may not be quite as benign as it first appears. Such sublethal effects may directly result in the death of

of organisms over an extended period, or more insidiously may impair the animals ability to withstand normal environmental stresses. Two measures of physiological function useful for investigating sublethal effects are respiratory metabolism and locomotory activity. Both may be severely impaired by exposure to low concentrations of dispersed crude oil we are still not in a position to predict, with any degree of confidence, the actual long-term ecological consequences of such physiological changes. An exposure that rapidly kills the animal is clearly significant. It is considerably more difficult to demonstrate unequivocally that a 30% reduction in metabolic rate or a 50% decrease in activity has adverse, long-term effects on a population. The effects are subtle, and the ultimate consequences are very much influenced by a wide range of inadequately known factors.

Species differences were evident in the behavioral responses to the presence of crude oil. Certain species appeared to be totally indifferent to the presence of the oil and readily ingested oil-tainted food and burrowed in oil contaminated sediments.

It marked contrast a number of other species exhibited a high degree of aversion to the oil; they tended to avoid oil masses, refused oil-contaminated food and overwhelmingly selected and burrowed in

clean in preference results suggest that the animals are capable of detecting very low concentrations of sediment bound oil. These diverse behavioral responses may play an important role in determining the physiologically effective dose of oil to which specific populations may be exposed. Furthermore, the pronounced disruption of feeding and burrowing behavior noted in some species could have far reaching implication regarding the continued survival of these populations.

The use of physiological data, acquired under carefully controlled laboratory conditions, to explain and anticipate biological events occurring in the 'real' world is a difficult enough exercise at the best of times. In the Arctic the process is rendered doubly difficult by the fact that our knowledge of conditions in the 'real' world is deplorably inadequate. To be overly dogmatic under such circumstances is to be less than realistic. At best it is possible to hint at simplistic adverse effects on specific populations arising from direct encounter with the oil. We are on far less firm ground in attempting to assess the wider long-term ecological repercussions of these primary effects.

The potentially severe biological effects outlined in this report are likely to have relatively limited ecological significance in the wake of a single oil spill during exploratory drilling, when considered on a broad geographic scale. Far greater impact can be anticipated from the cumulative effects of continuing minor and major spills during the production and transport of oil at multiple drilling sites. In the broader ecological context the critical point will be the relative balance between the accidental input of oil on the one hand and the rate at which the oil is removed from the environment by natural processes on the other hand. Indications are that in arctic seas the rate of input required to exceed the rate of natural removal will be considerably lower than in temperate and tropical seas. In heavily exploited regions the imbalance between the two could lead to oil concentrations over wide areas approaching that at which sublethal physiological and behavioral effects are operative. Every effort should be made to obtain theoretical estimates of the magnitude of each of these factors under a variety of conditions. Since the only means of rigorously testing such estimates is by monitoring an actual oil spill, a detailed program should be prepared now to intensively monitor the appropriate parameters in the event of an oil spill during proposed exploratory activities. Such information is essential for anticipating the potentially more serious ecological consequences of large scale production activity. In addition, further studies of sublethal physiological and be-

havioral effects are required to determine the minimum concentrations of oil in the environment that are sufficient to induce significant sublethal dysfunction in ecologically important species. The studies presented here are suggestive, but being of limited duration and scope must be considered little more than preliminary ground breaking.

Short-term studies, no matter how carefully executed, cannot be expected to adequately fill the void resulting from years of neglect of basic arctic marine research. It is unfortunate that the pace and scope of present attempts to fill this information void are more influenced by developmental and economic considerations than by carefully considered scientific judgement.

Areas of further research

To attempt to outline important areas of additional study is a formidable task, particularly in view of the fact that little reliable information is available at present about even the most basic ecology and physiology of the great majority of Arctic marine species. However, specifically with reference to direct effects of oil on marine ecosystems the following work is particularly important.

1. In view of its obvious vulnerability to oil spills we require further studies on the species composition, general ecology, trophic interrelationships, and ecological importance of the sub-ice community.

2. Further studies on the interaction between spilled oil and suspended sediment to better understand the rates of incorporation ecological impact and fate of crude oil in bottom sediments.
3. Studies of lethal and sublethal effects of crude oils on major arctic phytoplankton species and larval stages.
4. Further studies on sublethal physiological and behavioral effects to obtain realistic estimates of the minimum concentrations of crude oil at which demonstrable disruption of physiological functioning occurs, particularly following extended exposure to the pollutant. Such estimates of biologically critical concentrations will be particularly useful in conjunction with item number 5.
5. Studies on the time course of detoxification and elimination of spilled oil from arctic marine ecosystems in order to evaluate the relative balance between potential rate of input and the capacity of the system to cleanse itself. This is particularly important in relation to the critical concentration discussed in item 4.

